Report for 2001OK4441B: Springs in Peril: Have Changes in Groundwater Input Affected Oklahoma Springs?

- Other Publications:
  - Bergey, E. 2002. OBS Research Projects: A Survey of Oklahoma Springs. Biosurvey News. Oklahoma Biological Survey. Spring Newsletter, pp 3-4.

Report Follows:

Springs in Peril: Have Changes in Groundwater Input Affected Oklahoma Springs?

Problem and Research Objectives

Groundwater is an extremely important commodity to Oklahoma, with heavy use by agriculture, industry, municipalities, and private landowners. Groundwater is also critical for wildlife and for maintaining the high-quality outdoors environment of Oklahoma, especially through the influence of groundwater on springs and on stream flows.

Springs, by definition, are the areas where groundwaters emerge and become surface waters. As a habitat, springs share characteristics of both underground waters (nearly constant temperatures and water flow, and low oxygen concentration) and surface waters (light and algal growth, inputs of dead plant material, and the water-air interface which allows gas exchange and colonization by flying insects). Typically, springs have a characteristic fauna that may include certain fishes and a predominance of non-flying invertebrates, such as snails and flatworms.

The extensive use of groundwater in Oklahoma and surrounding states may reduce water levels in some Oklahoma aquifers, with consequent partial or complete dewatering of the associated springs. In fact, springs provide an excellent point to monitor quantitative and qualitative changes in groundwater resources (Williams and Danks, 1991). Such reduction in spring flows may adversely affect the plants and animals living in spring, especially those species that are spring specialists.

Objectives: The research will assess (1) the flow status of springs in Oklahoma, and (2) the effects of altered flow rates on spring biota. Discharge data and invertebrate surveys from 50 springs collected in 1981-1982 (existing data from a previous OWRRI project; Matthews et al.1983) and in 2001-2002 (this proposal) will be used to assess changes in groundwater discharge into springs and how these changes affect the invertebrate fauna of springs.

Specific objectives of the project are:

A. Estimate the extent of groundwater flow changes into springs throughout Oklahoma.
B. Determine if changes in spring conditions over the past 20 years have affected spring invertebrate communities.
C. Determine whether some types of springs are more susceptible to flow reduction than other types of springs.
D. Identify possible indicator species that either appear or disappear in flow-impacted springs.
E. Increase the knowledge base of the biodiversity and distribution of spring-dwelling invertebrates.
F. Train one graduate student to work on the springs of Oklahoma.
G. ‘Re-use’ data from the project by adding data to the OBS database, to be used, for example, in future research projects by external researchers.
H. Disseminate information and results in a final report, by developing a project website, presenting results at one or more meetings, and writing one manuscript.

Addition to objectives. In addition to sampling invertebrates at each spring, fish were collected, when present. Fish were collected in the 1981-1982 study and their inclusion in this study adds to the information gained about changes in the biota over the 20-year period. Fish were not included in the original proposal because there was insufficient time to obtain the required approval for research involving vertebrates by the University of Oklahoma. Approval has since been obtained (see copy of the letter in Appendix 1).

Methodology

The study hinges on the comparison of two datasets of spring surveys, one collected in 1981-1982 and the other collected in 2001. In order to have comparable surveys, the methods used in the 2001 springs survey closely followed those of the previous survey. Descriptions of the methods used in the 1981-1982 surveys are found in the final project report (Matthews et al. 1983), manuscripts (Matthew et al. 1985), and in the hardcopy files from the project.

Field sites. The 50 spring sites were originally selected because they had enough flow to be used as a water supply (with a few exceptions), were good sites for monitoring particular aquifers, and had landowner permission for privately owned sites. The 50 sites are located in 29 Oklahoma counties (Figure 1) and in 8 aquifers (Appendix 2).

The first step was to re-locate the 50 sites. Some sites were easily located; others were not. Difficult sites to find were not marked as springs on the 1:24,000 topographic maps and had known locations only to the section. Likely locations of springs were chosen from maps and county assessors kindly provided the names and addresses of potential landowners.

Each potential landowner was sent a letter explaining the project and asking permission to sample the spring. Also included was a questionnaire for owners to complete. The goal of the questionnaire was to get information on flow variability and flow trends over time, and land use changes that might not be apparent during one-time visits to the springs. A copy of the questionnaire is found in the Appendix 3A. Despite advance preparation, several sites were located by asking local residents.

As in the earlier survey, springs were surveyed during the summer. A standard data sheet was designed for the project, to ensure that complete set of data was collected at all sites. Data and samples collected at each spring included:

- A description of the spring site. This description included a diagram of the spring, directions to re-locate the site, GPS readings, and information on local land use, alterations to the spring, and the vegetation in and near the spring.
- Measurement of several physical and chemical parameters: including, pH; water temperature; conductivity; water widths, depths, and velocities. Discharge (the quantity of water flow per time, as liters per second) was calculated from the last three variables.

- Sampling for aquatic invertebrates. Qualitative sampling followed the 1981-1982 sampling protocol and included dip-netting, picking organisms off stones, and collecting leaf packs, which were preserved and later searched for invertebrates in the laboratory. Additionally, 3 to 6 core samples (diameter = 10.2 cm) were collected at each site. Invertebrate samples were preserved in 70% ethyl alcohol.
- Sampling for fish. Springs were seined with a fine-meshed (3 mm openings) seine and representatives of each species caught were preserved in 10% formaldehyde. The majority of captured fish were released.

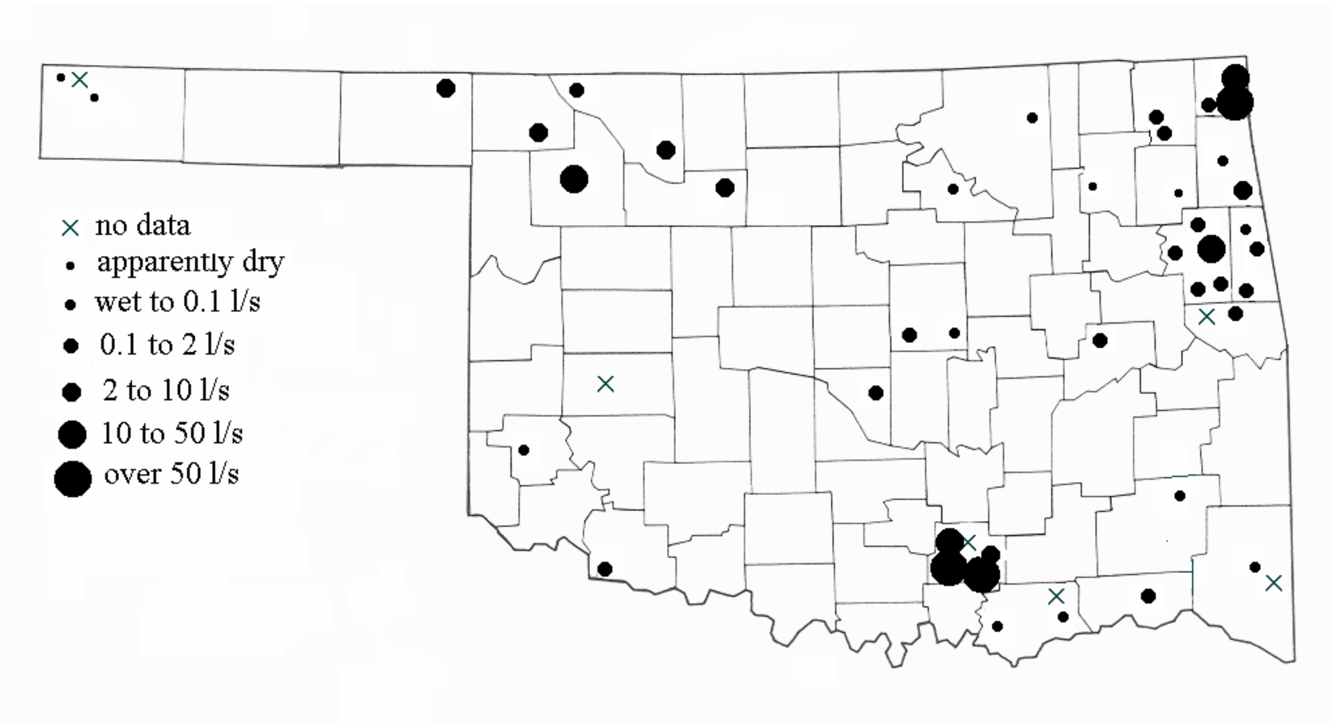


Figure 1. Location of the 50 springs sampled in 1981-82 and in 2001. The calculated discharge of each spring during the 2001 sampling is indicated by the symbol marking each spring (see legend).

Physical/chemical data (including water flows and habitat information)
Measurements for discharge were typically taken in the springbrook downstream of the springhead at a point were the water was relatively deep and there was an even bottom. In some cases, this was many meters below the springhead. Discharge was calculated by dividing the outflow stream into a transect of cells. The area of each cell was calculated as width x depth, and the cell-specific discharge was cell area x mean velocity of the cell. Velocities were measured with a Marsh-McBirney flow meter as feet/sec (to improve precision over a m/s reading). Depths were often very shallow (under 5 cm); but where deeper, velocities were read at 60% depth (the approximate mean velocity of the water column). At sites with an outflow through a pipe, discharge was measured as the time in seconds to nearly fill a one-gallon milk jug. All discharge measurements were converted to liters/second (= l/s).

Laboratory processing of biological samples. Fish samples were rinsed of formaldehyde, identified by Dr William Matthews (Curator of Fishes, Sam Noble Oklahoma Museum of Natural History, University of Oklahoma), and transferred to 70% ethyl alcohol. The fish samples will be curated (separated by species and appropriately labeled), and will be deposited in the fish collection at the SNOMNH.

Invertebrate collections are currently being processed. Most of the crayfish have been identified from 2001, and we are beginning to identify the crayfish from the earlier surveys (unfortunately, some of these samples were lost). Invertebrates in the qualitative (dipnet) and quantitative (core) samples are being separated from the detritus and substrate portions of each sample; a step that is necessary before invertebrates in the samples can be identified. Hence, the invertebrate data is not yet available for analysis.

Questionnaires. Questionnaires (see Appendix 3A) were completed for 39 of 50 sites. Landowners returned fewer than half of the questionnaires in the original mailing. Additional questionnaires were filled out by interviewing landowners during the fieldwork or during subsequent phone calls. Questionnaires were not completed where there was no identifiable 'owner' (especially sites on road easements) or owners who could not be contacted. Four questionnaires were 'completed' with no data because owners/managers were not very familiar with the springs. These four sites were the exception; most owners were very knowledgeable about their springs.

Summary of available data

- Site locations
- Discharge
- Questionnaire data
- Fish data
- Physical/chemical/habitat data

Site-specific locations. General location information for the 50 sites is found in Appendix 4. Most of the original sites were re-located exactly; exceptions are listed in Table 1. Access was denied at two sites; although partial information (and a completed questionnaire) was collected at one of these. One site (#40) was not a spring. This site was near a named spring (Gum Spring) and consisted of a hole that the landowner had dug with a backhoe next to the springbrook. I assume that the earlier field crew (which did not include the Principal Investigator) did not understand the nature of the 'spring'. Some of the areas contained several springs and in four of these, the actual spring that was sampled was probably not the one sampled in 1981-2.

Table 1. Problematic sites in which, (1) the exact spring that was sampled in 1981-2 was probably not relocated in the 2001 survey, (2) field data is incomplete, or (3) the site is not a spring.

Spring	Site specific information
3	access denied by owner
5,8,22, & 27	a cluster of springs; the one sampled in 2001 may not have been the same one sampled in 1981-1982
12	can't tell if its the same location (major habitat alteration)
29	site was recorded wrong in 1981-82; no springs nearby
38	owner restricted data collection
40	site sampled was not a spring
48	missing, presumed dried; possibly covered by logging road (which had a wet spot)

Principle Findings and Significance.

Discharge. Spring discharge ranged from 0 to 236 liters/minute (=l/m) with an average of 16 l/m. Spring-specific discharges are shown graphically in Figure 1 and listed in Table 2. Several sites had no discharge, either because there was standing water but no outflow, or the spring was dry.

Discharge varied among aquifers (aquifers are shown in Appendix 2). The Simpson/Arbuckle Group (in the Arbuckle Mountains) had the highest average discharge of about 77 l/s. At the other extreme, three aquifers (the Trinity Group, Garber Sandstone, and Vamoosa Formations) had mean discharges of less than 1.0 l/s. The Ogallala Aquifer averaged 3.2 l/s, despite two of the three springs being dry. The third spring (# 27) is located near the division of the Ogallala Aquifer and the alluvial & terrace deposits near the Cimarron River; if the spring is actually has an alluvial / terrace origin, the mean flow for the measured Ogallala sites would be 0.0 l/s.

The flow 'health' of an aquifer may be indicated by a comparison between the mean spring discharge and the potential yield of the aquifer. The resulting percents of spring discharge to historic potential yield are shown in Table 3. Springs in the Keokuk & Reeds Springs Formations and the Simpson / Arbuckle have mean discharges exceeding the estimated maximum yields from the aquifers, indicating that these sets of springs have a 'healthy' discharge. In contrast, springs in the Trinity Group have discharges that are small relative to the historical potential yields, which may indicate reduced discharges since 1972 in these springs. Garber Sandstone and Vamoosa Formations likewise have relatively small average discharges, but the sample size of only two springs in each is too small to draw conclusions. The Ogallala Formation has a moderate percent discharge, but if spring # 27 is instead an alluvial / terrace spring, the percent discharge drops to zero (there is no flow).

Table 2. Site-specific discharge of the 50 springs, as measured in summer, 2001. Aquifers were designated as in 1981-2. For Discharge, 'NA' = not available, '0' = spring had standing water but no outflow, '0.0 (dry)' = spring was dry. Springs with fish are also indicated.

Spring number	Discharge (l/s)	Aquifer	Notes	Fish present?
1	7.2	Simpson	water is pumped for a fish farm	yes
2	NA	Simpson	spring is in a flow-through pond	yes
3	NA	Trinity	denied access by owner	
4	0	Trinity		
5	0.02	Trinity		
6	136.2	Simpson		yes
7	28.98	Simpson		yes
8	136	Simpson		
9	0.11	alluvial and terrace		
10	0.0 (dry)	alluvial and terrace		
11	0.33	Keokuk & Reed		
12	0	Keokuk & Reed		yes
13	9.84	Keokuk & Reed		
14	0.41	Keokuk & Reed		
15	0.09	Keokuk & Reed		
16	12.81	Keokuk & Reed		
17	1.87	Keokuk & Reed		yes
18	1.7	Keokuk & Reed		
19	1.76	Keokuk & Reed		yes
20	1.56	Keokuk & Reed		
21	1.1	alluvial and terrace		yes
22	2.6	alluvial and terrace		yes
23	4.31	alluvial and terrace		yes
24	0.67	alluvial and terrace	shoreline seeps not included	
25	3.83	alluvial and terrace		
26	12.67	alluvial and terrace		
27	9.67	Ogallala		yes
28	0.0 (dry)	Ogallala		
29	NA	Ogallala	site was not found	
30	0.0 (dry)	Ogallala		
31	0	Vamoosa		
32	0.02	Vamoosa		
33	0.0 (dry)	alluvial and terrace		
34	0.24	alluvial and terrace		
35	0.24	Keokuk & Reed		yes
36	0.11	Keokuk & Reed		
37	46.91	Keokuk & Reed		yes
38	236.14	Keokuk & Reed		yes
39	0.58	Keokuk & Reed		

Spring number	Discharge (l/s)	Aquifer	Notes	Fish present?
40	NA	alluvial and terrace	not a spring	
41	0.67	alluvial and terrace		
42	0	alluvial and terrace	some may be pumped by neighbor	
43	NA	Rush	inundated	yes
44	0.44	Garber Sandstone		
45	0.59	Garber Sandstone		
46	0.073	alluvial and terrace		yes
47	0	Trinity		
48	0	Trinity		
49	0	Trinity		yes
50	0.19	Trinity		

Table 3. Aquifer-specific discharge of the 50 springs in the study. SE = +/- 1 standard error from the mean.

Aquifer	Total no. of springs	No. of dry springs[1]	No. of springs used in calculation[1]	Mean discharge (l/s) (SE)	Maximum yield of aquifer[2] (l/s)	Mean as % of maximum yield
Keokuk & Reeds Springs Formations	15		15	21.0[3] (15.7)	3.2	665.6
alluvium & terrace deposits	14	2	12	2.2 (1.05)	31.6	7.0
Trinity Group (Antlers Sandstone)	7		6	0.04 (0.03)	63.1	0.06
Simpson / Arbuckle Groups	5		4	77.1 (34.4)	18.9 157.8	407.3 48.9
Ogallala Formation	4	2	3	3.2 (3.2)	63.1	5.1
Garber Sandstone / Wellington Formation	2		2	0.5 (0.1)	18.9	2.6
Vamoosa Formation	2		2	0.01 (0.01)	9.5	0.1
Rush Springs Sandstone	1		0		31.6	

[1] Not all possible springs were used in calculating aquifer-specific mean discharges or determining dry springs because some springs were not found and / or discharge could not be accurately measured.
[2] Data are modified by conversion of units from Johnson et al. 1972.
[3] If site #38 (a very high discharge site) is excluded, the mean drops to 5.6 l/s (SE = 3.3).

Other indicators of spring 'health'. Changes in the discharge of individual springs were assessed by (1) comparing velocity and discharge data among years and (2) examining the responses in the owner questionnaires. Unfortunately, the flow data from 1981 was not as detailed as expected and earlier discharges could not be calculated. The exception was site #

50, in which the water flowed out of a pipe, and timing the filling of a container gave a good discharge measurement. Additionally, velocities were listed as 'negligible' or 'unmeasurable' for 18 springs in 1981. Data from 1982 were scantier. Instead, velocity, depth and width (components of discharge) were compared among years, and changes in sketches of the sites were also noted. In the questionnaires, owners were specifically asked whether spring flow had changed during the last 20 years (see questionnaire form in Appendix 3A). Spring-specific results are shown in Appendix 5.

The questionnaire data, although incomplete, provide a clearer picture of temporal flow changes in the springs. Owner knowledge (as sampled by the questionnaire) is not hampered by comparisons between two different field teams that each used a different method to describe flows, or by the point measurements of flow 20 years apart (when flow is likely variable from year-to-year). Unfortunately, not all owners were familiar with their springs throughout the period, nor were questionnaires completed for all sites. Questionnaire data, supplemented and amended by field data, were used for temporal analysis.

Thirty-two (64 %) of springs were classified for relative change in discharge over the 20-year period (Appendix 5). Over one-half (63 %) of these springs showed no change in discharge over the interval.

Relative change in discharge differed among aquifers (Table 4). Of seven aquifers, only two, the Simpson/Arbuckle and Garber Sandstone, had springs that all remained relatively constant. Both of these aquifers also had two or fewer springs with data, so this pattern may not hold for the aquifers' springs, as a whole. Discharge in most Keokuk & Reed Formation springs remained unchanged, but 20 % of these springs showed a decrease in discharge. Alluvium and terrace springs are a group of springs from several rivers that span most of the state. Hence, it is not surprising that the terrace alluvial springs vary in their temporal change. Although flow in most alluvium and terrace springs did not change, one spring had reduced discharge and, more notably, two springs dried. The dried alluvial/terrace springs are located in NE Oklahoma in the Verdigris River watershed.

Table 4. Summary of relative temporal change on spring discharge between 1981-82 and 2001. Data are from the table in Appendix 5 and are derived primarily from landowner questionnaires. Data are listed as 'number of springs' and as percentages of the springs with data (in parentheses).

	Number of springs					
Aquifer	**Total**	**With data**	**No change**	**Decrease**	**Dry**	**Increase**
Keokuk & Reed	15	10	8 (80 %)	2 (20 %)		
alluvium & terrace	14	10	7 (70 %)	1 (10 %)	2 (20 %)	
Trinity	7	5	2 (40 %)	2 (40 %)		1 (20 %)*
Simpson/Arbuckle	5	2	2 (100 %)			
Ogallala	4	2			2 (100 %)	
Garber Sandstone	2	1	1 (100 %)			
Vamoosa	2	2		2 (100 %)		
Rush	1	0				

* = The increased discharge of one spring was probably the result of a new outflow pipe that was installed by the county the previous year.

Springs associated with three aquifers were characterized by reductions in discharge over the 20-year period. Forty percent of the springs in the Trinity aquifer and all springs in the Vamoosa aquifer had noticeably reduced discharge, and both Ogallala springs dried. Each of these aquifers had few springs with data and additional data is needed to substantiate these preliminary findings.

Fish. The fish data have only been partly analyzed.

A total of 26 species of fish were found in 21 springs over the course of the three surveys (Appendix 6). In any year, fish were found in 14 to 18 springs; thus, there is year-to-year variation in which springs have fish at the time of sampling. Most of the fish species found in the springs are also common in streams, and fish may move between springs and streams. Hence, the absence of a fish species in a spring during some years may result from fish movements, combined with a one-time sampling (that is, fish that may normally be present may not be caught during sampling).

Overall, the fish fauna differed among springs and was characterized by a large number of species that occurred infrequently. Five species were common, occurring in 25 % or more of samples; in contrast, 11 species were collected only once during the three years of sampling.

Plans for this year. The questionnaire has been revised (see Appendix 3B), with the hope of (1) getting more specific information from landowners and (2) adding a request for historical use of springs. About 100 questionnaires (along with information about the study) will be mailed to potential owners of springs by the end of March. Some of these springs will be sampled as part of this project.

This summer, I will extend the fieldwork to include 20 to 30 additional springs. Springs in sparsely sampled aquifers. Such aquifers include the Trinity / Antlers Sandstone Group in the southeast corner of Oklahoma, and the Ogallala aquifer in the northeast corner of the state.

References:

Johnson, K. S., C. C. Branson, N. M. Curtis, Jr., W. E. Ham, W. E. Harrison, M. V. Marcher, and J. F. Roberts. 1972. Geology and Earth Resources of Oklahoma: An Atlas of Maps and Cross Sections. Oklahoma Geological Survey. 8 pp.

Matthews, W. J., J. J. Hoover, and W. B. Milstead. 1983. The biota of Oklahoma springs: Natural biological monitoring of ground water quality. Misc. Publ. Oklahoma Water Research Institute, Oklahoma State University, Stillwater, Oklahoma. 64 pp.

Matthews, W. J., J. J. Hoover, and W. B. Milstead. 1985. Fishes of Oklahoma springs. Southwest Nat. 30:23-32.

Williams, D. D., and H. V. Danks.1995. Arthropods of springs: Introduction. Mem. Ent. Soc. Canada 155:3-5.

List of Appendices

The University of Oklahoma

LABORATORY ANIMAL RESOURCES

May 17, 2001

Beth McTernan
Assistant Director
Environmental Institute
003 Life Sciences East
Stillwater, OK 74078-3011

RE: WR-01-RS-001B
Principal Investigator, Elizabeth Bergey

Dear Ms. McTernan:

The following application submitted to OWRRI was reviewed and approved by this institution's Animal Care and Use Committee on May 17, 2001:

Title of Application:	"Springs in Peril: Have Changes in Groundwater Input Affected Oklahoma Springs?"
Principal Investigator:	Elizabeth Bergey, Oklahoma Biological Survey
Institution:	The University of Oklahoma

This approval is for the period through 28 February 2003. This institution has an Animal Welfare Assurance on file with the Office for the Protection of Research Risks. The Assurance Number is A3240-01.

Sincerely yours,

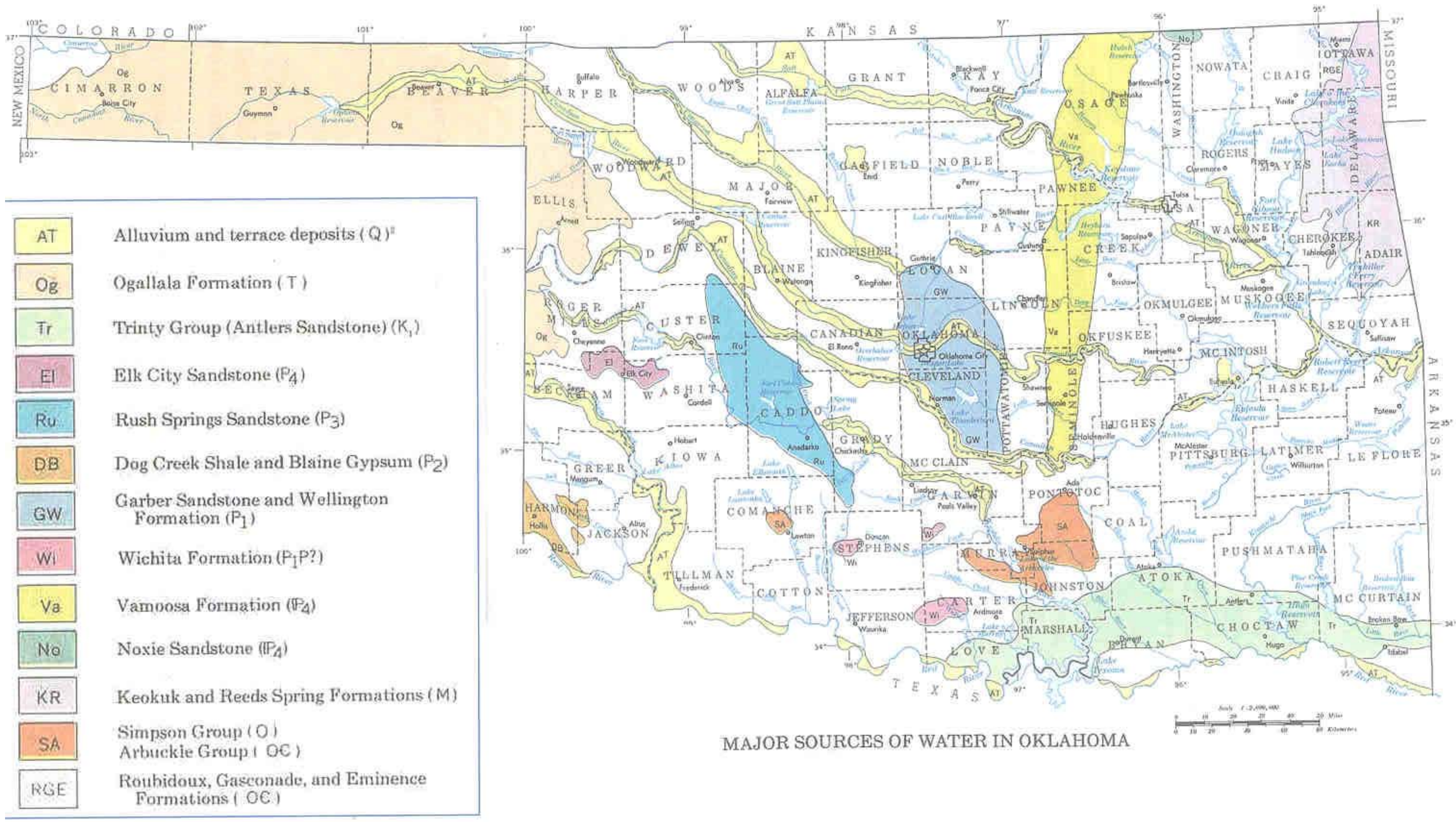
John Lancaster
Chairman
Animal Care and Use Committee

JL/ke

cc: Elizabeth Bergey

770 Van Vleet Oval, Room 135, Norman, Oklahoma 73019-0245 PHONE: (405) 325-2609

Appendix 2. The aquifers of Oklahoma (modified from Johnson et al. 1972)



Appendix 3A. Owner questionnaire used in 2001.

Spring name:
Spring location:
Owner:

1. Were you the property owner in 1981?
   If not, about how long have you owned the property? ________, and is there a person who might be more familiar with the spring over the last 20 years?

2. Does the spring ever dry completely? _______ Or dry only to an isolated pool? _______
   How often and how long?

3. Circle any of the recent summers in which the spring dried: 1997 1998 1999 2000

4. Is the flow steady during the year (for example is the flow the same in winter and summer)?

5. Does the water flow from the spring sometimes increase after rains?

6. Have you noticed that the water flow in the spring has shown a pattern of change over the years? _____. In particular, has the flow tended to (circle one)

   increase a lot   increase slightly   not change   decrease slightly   decrease a lot

7. Do you know what may cause this water flow pattern? (if one was observed)

8. Have there been any land use changes in the vicinity of the spring or alterations to the spring in the past several years? (as examples, has grazing changed or has the spring been dammed?)

9. May I contact you for further information? _____ How may I contact you?
   ____

Appendix 3B. Questionnaire form for 2002 field season. (Spaces have been reduced.)

Spring name: Owner:
Spring location:

1. About how many years have you owned the property with the spring? _______
2. How familiar are you with your spring? (For example, do you see the spring frequently and would you notice year-to-year changes?) ________________________________
(Note: if you know somebody who is more familiar with the spring, please give them this questionnaire or let me know, so that I can send them a questionnaire).
____
____
3. How has the spring been modified from the natural state (for example, does it have a spring box? has the springbrook been dammed to make a pond?) ___________________________________
____
How is the spring used now? ____
How has it been used in the past? ____
4. Check the description that matches your spring in the past few years (= Now) and in the past (=Past). This gives me an idea of what sorts of animals may live in your spring and whether the water flow I your spring is changing. Check all that apply.

Now	Past	
___	___	1. to my knowledge, the spring has never dried
___	___	2. runs well year-around in all years
___	___	3. runs year around in all years, but flow increases after rains
___	___	4. runs year around in all years, but flow decreases during dry weather
___	___	5. normally runs year around, but stops flowing (stays wet) in dry weather
___	___	6. normally runs year-around, but dries completely in very hot, dry weather
___	___	7. runs most of the year, but stops running (stays wet) when it's very dry
___	___	8. runs most of the year, but dries during the summer
___	___	9. is generally wet, but flows when there weather is wet
___	___	10. is generally wet year-around
___	___	11. is dry, but runs briefly after rains or wet weather
___	___	is dry and never runs

Comments, especially if the pattern of flow has changed or none of these fits your spring:

5. Has the area around the spring changed over the past several years? If so, How? (for example: no longer grazed; now dammed, springbox removed)
6. May I contact you for further information? __________ How may I contact you?
____

Appendix 4. Locations of the 50 springs that were sampled in 1981, 1982 and 2001. Locations are
given to the nearest section to because most sites are privately owned and many owners did not want the exact locations disclosed. The date of the 2001 sampling is also listed.

Site	County	T/R/Sec	Date	Site	County	T/R/Sec	Date
1	Bryan	T1S R6E Sec.24	7/5/01	26	Woodward	T23N R20 Sec 23	6/19/01
2	Johnston	T1S R6E S12	9/25/01	27	Beaver	T5N R26E Sec 1	6/20/01
3	Bryan	T5S R12E S33	no access	28	Cimarron	T6N R50W Sec 31	6/20/01
4	Bryan	T6S R11E Sec 1	7/10/01	29	Cimarron	T6N R1E Sec 28?	not found
5	Bryan	T6S R7E Sec 24	7/10/01	30	Cimarron	T6N R4E Sec 10	6/20/01
6	Johnston	T1S R6E Sec 24	7/5/01	31	Pawnee	T22N R6E Sec 26	6/26/01
7	Johnston	T1S R6E Sec. 22	8/10/01	32	Osage	T25N R11E Sec 10	6/26/01
8	Johnston	T1S R6E Sec. 22	8/10/01	33	Rogers	T22N R15E Sec 10	6/26/01
9	McIntosh	T12N R15E Sec 5	7/13/01	34	Rogers	T24N R18E Sec 3	6/27/01
10	Mayes	T20N R20E Sec 4	7/28/01	35	Craig	T24N R21E Sec 11	10/4/01
11	Cherokee	T19N R21E Sec 35	7/17/01	36	Ottawa	T26N R24E Sec 8	6/27/01
12	Delaware	T22N R24E Sec 29	7/28/01	37	Ottawa	T27N R25E Sec 31	6/28/01
13	Delaware	T20N R25E Sec 36	7/17/01	38	Ottawa	T27N R25E Sec 31	6/28/01
14	Adair	T17N R26E Sec 9	7/19/01	39	Sequoyah	T13N R23E Sec 19	7/12/01
15	Adair	T18N R25E Sec 31	7/19/01	40	Sequoyah	T13N R21E Sec 8	7/12/01
16	Cherokee	T17N R22E Sec 33	7/18/01	41	Tillman	T4S R17W Sec 14	7/2/01
17	Cherokee	T17N R21E Sec 12	7/17/01	42	Greer	T6N R24W Sec 25	7/2/01
18	Cherokee	T15N R22E Sec 9	7/17/01	43	Washita	T10N R14W Sec 35	7/2/01
19	Cherokee	T15N R23E Sec 22	7/17/01	44	Cleveland	T10N R1W Sec 14	6/14/01
20	Adair	T14N R24E Sec 4	7/17/01	45	Lincoln	T12N R2E Sec 25	6/14/01
21	Garfield	T21N R8W Sec 26	6/22/01	46	Okfuskee	T12N R7E Sec 25	6/14/01
22	Major	T22N R10W Sec 27	6/22/01	47	McCurtain	T4S R24E Sec 27	7/11/01
23	Woods	T23N R15W Sec 13	6/21/01	48	McCurtain	T5S R25E Sec 1	7/12/01
24	Woods	T28N R18W Sec 2	6/21/01	49	Pushmataha	T1S R19E Sec 30	7/11/01
25	Harper	T26N R20W Sec 12	6/21/01	50	Choctaw	T6S R17E Sec 20	7/10/01

Appendix 5. Summary of results from field data and owner questionnaires on whether discharge in the 50 study springs has changed over the last 20 years. Because discharge was not measured in 1981-82, field data comparisons are limited to comparisons of water velocity and depth, spring width, and diagrams / measurements of each spring. Only data in the Questionnaire column was used for further analysis.

Spring number	**Field data: Change since 1981?**	**Field data: Notes**	**Questionnaire: Change since 1981?**
1	possibly reduced	lower velocity & depth	no
2	can't tell	habitat alterations	no
3		denied acess	
4	possibly reduced		decreased a lot
5	can't tell	not the same spot	no
6	can't tell	inadequate data	no
7	no evidence of change		unsure
8	can't tell	spring may have shifted	unsure
9	no evidence of change		no
10	apparently dry		[dry]*
11	can't tell	springbox had broken	no
12	can't tell	habitat alteration	no
13	possibly reduced	1 of 2 seeps was dry (or shifted)	no
14	can't tell	heavy siltation	no
15	possibly reduced	habitat alteration	no
16	can't tell	inadequate data	no
17	can't tell	habitat alteration	
18	possibly reduced	lower velocity & depth	
19	no evidence of change		
20	no evidence of change		decrease noticeably
21	possibly decreased	habitat alteration	no
22	no evidence of change		
23	no evidence of change		no
24	no evidence of change		no
25	no evidence of change		no
26	no evidence of change		decrease a bit
27	can't tell	same site?	seems deeper
28	dried		dried; decreased since 70's
29	can't tell	not found in 2001	
30	apparently dry		dried; ran in 1999 (wet yr)
31	apparently reduced	too low for a water supply	no [decrease]*
32	no evidence of change		decrease slightly
33	dried		[dry]*
34	no evidence of change		
35	possibly reduced	lower velocity; smaller pond	no
36	no evidence of change		
37	can't tell	spring shifted; slight increase?	decrease slightly
38	no evidence of change		no

39	possibly reduced	habitat altered; reduced vel. & width	
40	no evidence of change		no
41	no evidence of change		no
42	no evidence of change		no
43	can't tell	inundated; increase in adjacent stream	increase slightly [unsure]*
44	can't tell	overgrown with rushes	no
45	can't tell	inadequate data	
46	no evidence of change	pools appear bigger (erosion?)	
47	no evidence of change		decrease slightly
48	can't tell	possibly covered by logging road	
49	no evidence of change		
50	increased	greater discharge from new pipe	increase slightly

* Data in brackets was added from the field notes and consists of two dried springs (# 10 and # 33), a spring (# 31) that was used as a drinking water source in 1981-82, but did not flow in 2001, and a spring (# 43) was inundated by an impoundment and wasn't visible (the adjacent stream increased in flow as it was intermittent in 1981-82 and flowing in 2001).

Appendix 6. The occurrence of fish in the sampled springs. Data are from 1981,1982, and 2001. Fish were sampled qualitatively and data are in a presence (= 'x') / absence (= blank) format. A summary
end of the table.

Spring number	1	1	1	2	2	2	6	6	6	7	7	7	8	12	12	16	17	17	17	18
Fish species / **Year**	1981	1982	2001	1981	1982	2001	1981	1982	2001	1981	1982	2001	1982	1981	1982	1981	1981	1982	2001	1981
Ameiurus melas																				
Ameiurus natalis																				
Campostoma anomalum	x		x	x	x	x	x	x	x				x							
Cottus carolinae																				
Cyprinella lutrensis																				
Etheostoma cragini																				
Etheostoma microperca	x	x	x							x	x	x	x							
Etheostoma radiosum																				
Etheostoma spectabile	x	x	x	x	x	x	x	x	x		x	x			x		x	x	x	
Etheostoma whipplei																				
Fundulus notatus															x					
Fundulus zebrinus																				
Gambusia affinis	x	x	x	x	x	x	x	x		x		x	x	x	x					
Labidesthes sicculus															x					
Lepomis cyanellus			x		x			x						x	x					
Lepomis cyanellus ?																				
Lepomis humilus																				
Lepomis macrochirus															x					
Lepomis megalotis																				
Luxilus cardinalis																				
Luxilus chrysophelalus									x											
Micropterus salmoides																				
Notemigonus crysoleucas																				
Notropis stramineus																				
Phoxinus erythrogaster	x	x	x				x	x	x			x			x	x				x
Pimephales promelas																				
Semotilus atromaculatus															x					

Appendix 6. Continued.

Spring number	18	18	21	21	22	22	22	23	23	27	33	35	35	35	37	37	37	38	38	38	43
Fish species Year	1982	2001	1981	1982	1981	1982	2001	1981	2001	2001	1982	1981	1982	2001	1981	1982	2001	1981	1982	2001	1981
Ameiurus melas				X																	
Ameiurus natalis			X																		
Campostoma anomalum							X				X	X	X								
Cottus carolinae															X	X	X	X	X	X	
Cyprinella lutrensis			X	X	X	X	X														
Etheostoma cragini												X	X	X							
Etheostoma microperca																					
Etheostoma radiosum																					
Etheostoma spectabile													X	X							
Etheostoma whipplei																					
Fundulus notatus																					
Fundulus zebrinus			X		X	X	X														
Gambusia affinis										X		X	X	X							
Labidesthes sicculus																					
Lepomis cyanellus			X	X		X															
Lepomis cyanellus ?									X												
Lepomis humilus			X																		
Lepomis macrochirus																					
Lepomis megalotis			X	X		X															X
Luxilus cardinalis																X					
Luxilus chrysophelalus																					
Micropterus salmoides								X	X												
Notemigonus crysoleucas				X																	
Notropis stramineus					X	X	X														
Phoxinus erythrogaster	X	X														X					
Pimephales promelas			X	X							X										
Semotilus atromaculatus																					

Appendix 6. Continued

Spring number	43	44	46	46	46	49	49	49
Fish species Year	1982	1981	1981	1982	2001	1981	1982	2001
Ameiurus melas								
Ameiurus natalis								
Campostoma anomalum						x	x	x
Cottus carolinae								
Cyprinella lutrensis	x							
Etheostoma cragini								
Etheostoma microperca								
Etheostoma radiosum						x	x	x
Etheostoma spectabile								
Etheostoma whipplei					x			
Fundulus notatus								
Fundulus zebrinus								
Gambusia affinis		x	x	x				
Labidesthes sicculus								
Lepomis cyanellus			x	x	x		x	x
Lepomis cyanellus ?								
Lepomis humilus								
Lepomis macrochirus								
Lepomis megalotis	x							
Luxilus cardinalis								
Luxilus chrysophelalus								
Micropterus salmoides								
Notemigonus crysoleucas								
Notropis stramineus								
Phoxinus erythrogaster								
Pimephales promelas	x							
Semotilus atromaculatus								

	Number of springs			No. of
Fish species Year	1981	1982	2001	records
Ameiurus melas	0	1	0	1
Ameiurus natalis	1	0	0	1
Campostoma anomalum	5	6	5	16
Cottus carolinae	2	2	2	6
Cyprinella lutrensis	2	3	1	6
Etheostoma cragini	1	1	1	3
Etheostoma microperca	2	3	2	7
Etheostoma radiosum	1	1	1	3
Etheostoma spectabile	4	7	6	17
Etheostoma whipplei	0	0	1	1
Fundulus notatus	0	1	0	1
Fundulus zebrinus	2	1	1	4
Gambusia affinis	8	7	5	20
Labidesthes sicculus	0	1	0	1
Lepomis cyanellus	3	7	3	13
Lepomis cyanellus ?	0	0	1	1
Lepomis humilus	1	0	0	1
Lepomis macrochirus	0	1	0	1
Lepomis megalotis	2	3	0	5
Luxilus cardinalis	0	1	0	1
Luxilus chrysophelalus	0	0	1	1
Micropterus salmoides	1	0	1	2
Notemigonus crysoleucas	0	1	0	1
Notropis stramineus	1	1	1	3
Phoxinus erythrogaster	4	5	4	13
Pimephales promelas	1	3	0	4
Semotilus atromaculatus	0	1	0	1